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DEPARTMENT OF COMMERCE AND LABOR
BUREAU OF FISHERIES
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DEVILS LAKE, NORTH DAKOTA

A STUDY OF PHYSICAL AND BIOLOGICAL CONDITIONS, WITH A VIEW TO THE ACCLIMATIZATION OF FISH

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By Thomas E. B. Pope
Assistant, Bureau of Fisheries

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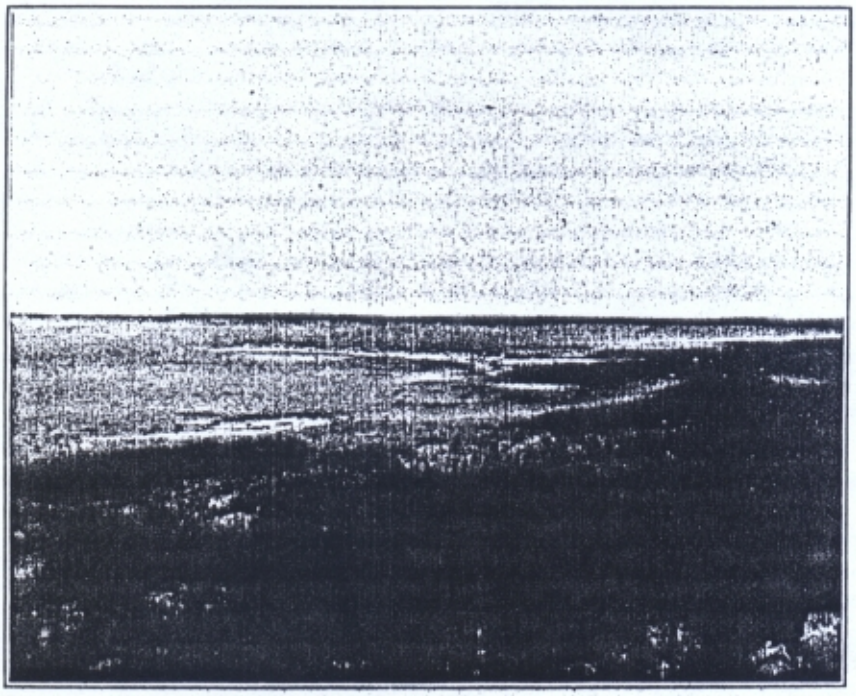
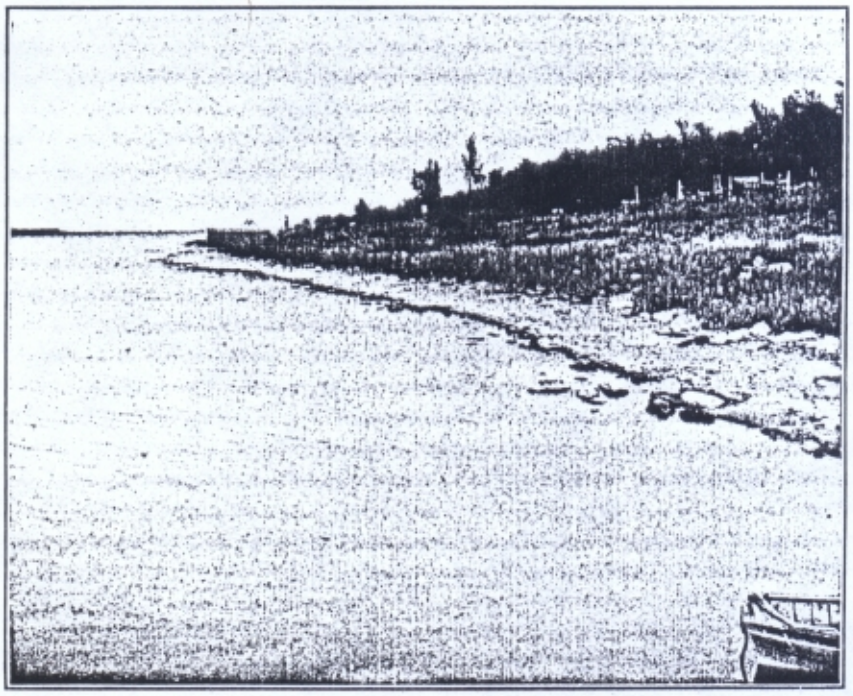


NORTHERN SHORE OF DEVILS LAKE.



EASTERN SHORE OF CREEL BAY.

DEVILS LAKE, NORTH DAKOTA.

JDY OF PHYSICAL AND BIOLOGICAL CONDITIONS, WITH A VIEW TO THE ACCLIMATIZATION OF FISH.

By Thomas E. B. Pope,
Assistant, Bureau of Fisheries.

nce the sudden disappearance of pickerel from Devils Lake about) no species of food or game fish has been found in its waters. s has been the subject of much concern to residents of that locality, in response to repeated inquiries as to its cause and urgent re- sts that the lake be stocked with fish, the Bureau of Fisheries :ituted investigations into the conditions now obtaining in that ality. These investigations, embracing a period of seven weeks, m July 20 to September 10, 1907, form the basis of the following ort.[a]

DESCRIPTION.

Devils Lake is an irregular sheet of water 30 miles long, lying in amsey and Benson counties. Along its entire south shore is an ıbroken ridge of prominent and typical morainal hills rising in rong contrast to the level farm land bordering its northern extent. 'rior to 1889 the Mauvaise Coulée at its northwestern end maintained onnection with Lake Irvine and thence through small creeks with)ry and Sweetwater lakes, directly north of Devils Lake, the whole orming a U-shaped system. At present there is neither inlet nor ıutlet, Mauvaise Coulée being reduced to a dry creek bed, except luring the spring freshets and periods of unusual rainfall.

By reason of the rapid lowering of its level and the consequent radical changes in configuration during the past twenty-five years, Devils Lake has been broken up into detached portions or large areas narrowly connected. The most important section from an economic

[a] The investigating party consisted of the writer, Mr. E. L. Goldsborough, and Mr. W. F. Hill, all from the Bureau of Fisheries. Residents of the locality rendered valuable assistance and numberless courtesies throughout the work.

standpoint is the larger and deeper portion—called the Main Lake—lying in the central portion of the present lake system, extending from Grahams Island on the west to the highway at the southern extremity of Roque Island on the east. This occupied the attention of the party for the major part of the investigations, though all sections and surrounding waters were inspected and observations made thereon.

A brief hydrographic survey of the Main Lake was made, a number of triangulation points being established along its shores and signals erected at favorable sites. The projection of range lines to the water's edge and the location of section corners near the lake shore were of great value in this connection, photolithographic copies of township plats bordering upon the lake being furnished by the United States General Land Office. The lines of soundings consisted of a system of transverse zigzags from shore to shore with a few lines along the axis of the lake and occasional diagonals to check results. The lines were run with the aid of small gasoline launches, soundings being taken by lead line and positions ascertained by sextant observations at about five-minute intervals. At each station temperature and density observations, water specimens, and plankton hauls were taken and recorded. The biological features of the lake received careful consideration, and collections representative of the fauna and flora were made.

The lake is located in a district of small rainfall and the excess of evaporation over precipitation has reduced the area and caused the desiccation of many shallow tributary bays. It has so decreased the depth that across the narrower portions of the lake highways have been constructed, thus anticipating the natural isolation of its component portions. Lamoreau Bay is isolated by a highway at its western extremity; from the southern point of Roque Island another public road and railroad trestle have been constructed, and these with the shallow across the narrows at La Rose Ferry divide the lake into four sections. Of these the middle section, lying between the Great Northern Railroad trestle and La Rose Ferry, is the deepest and most important. The entire western end of the old lake is now converted into barren, weed-grown tracts of land, the alkaline deposit on the soil and rocks that once formed its shores outlining its former area, and Mauvaise Coulée opens into a detached pond, the narrow irregular tributary formerly leading to it being cut off. Devils Lake city, formerly touched by the northern end of Creel Bay, is at present 1½ miles distant from the shore. The major portion of Mission Bay, an arm extending into the Sioux Indian Reservation, on the southern shore of the lake, has been entirely cut off from the parent body and is now known as Mission Lake; another portion, Large Mission Bay, is dried up; while an-

other and smaller remnant, known as Mission Bay, is practically isolated. A study of the accompanying chart shows the diminished area by comparison of the shore line charted by the United States Geological Survey in 1883 with that shown by the present investigations in 1907. The total area of the lake approximates 102.75 square miles, inclosed in a basin 40.5 miles long by 8 miles wide.

The shore line is very irregular, the character in general being similar to that of a marine littoral, bowlders, wholly or partly incrusted with a white alkaline deposit, and gravelly or sandy stretches occurring throughout its extent.

The floor of the lake is practically level, rising from a depth of 25 feet to the shallow portions near the shores or forming sand bars and stony reefs at mouths of bays. In general the deepest area is that of the southern side under the lee of the morainal ridges of Sullys Hill and Fort Totten, while the entire western section beyond La Rose Ferry is but 3 feet deep, with underlying soft black mud supporting an abundance of weeds and inaccessible to all but the lightest draft boats. West of Grahams Island the lake is almost dried up, two or three small ponds being the sole vestiges of a once broad expanse of water. The northern ends of Creel and Six-Mile Bay are desiccated and the eastern portion of the main section, at the southern end of Roque Island and contiguous to the railroad trestle, has rapidly shoaled with sand bars and reefs within 1 or 2 feet of the surface. The narrower portions of the lake are rapidly contracting and in general it may be said that it is rapidly becoming broken up into detached bodies, these in turn diminishing in size.

For purposes of this report the lake may be divided into four natural sections as follows: (1) The main section, including the deepest and most important part of the lake, from the narrow pass at La Rose Ferry to the public highway and railroad trestle of the Great Northern Railroad; (2) the eastern section, from the eastern limit of the main section to Lamoreau Bridge; (3) Lamoreau Bay, the detached extreme eastern portion of the lake system; (4) the western section, comprising all remaining water west of La Rose Ferry to Minnewaukan and Mauvaise Coulée.

MAIN SECTION.

From La Rose Ferry to the Great Northern Railroad bridge the main section extends for about 8 miles, and its greatest breadth from the mouth of Creel Bay to the wharf at Fort Totten is about 5½ miles, embracing a total area of 34.50 square miles. Into its northwestern end opens Six-Mile Bay, into its mid-northern shore Creel Bay, and into its southeastern end Little Mission Bay.

This beautiful section teemed with pickerel prior to 1889. In the "narrows" directly north of Roque Island these fish were speared and taken by hook literally by tons until their remarkable disappearance that year. They averaged 5 pounds, many individuals attaining a weight of 17 to 18 pounds. The northern end of Creel Bay beyond the "narrows" (marking the present limit of the bay) was perhaps the largest spawning ground for pickerel, though Large Mission Bay, now dried up, was also important. Six-Mile Bay shows no evidence of having furnished spawning beds, unless to a very limited area of the extreme northern end.

The maximum depth found was not greater than 25 feet. It was 35 feet in 1883, the date of the survey by the Department of the Interior. In general the bottom is composed of soft black mud, is very level, and gradually ascends to the sandy, gravelly, or rocky shores. The average density of the water in this section is 1.006.

Creel Bay.—This, the most important arm of the main section of Devils Lake, extends in a northeasterly direction for about 3½ miles, with an average width of one-half to three-fourths mile. Soundings showed an average depth of about 15 feet, with a maximum of 23 feet at the mouth of the bay. In general the shores are gravelly and rocky. Meteorological and other observations were conducted at the grounds of the North Dakota Chautauqua Association, where also was established the bench mark and tide gauge of the U. S. Geological Survey described in later pages of this report.

In this bay a remarkable wealth of plankton was obtained both in the deeper portions and along the shallow and weed-grown rocky shores, in certain localities being so abundant that the water was as if filled with sediment. A species of light-green alga attached itself to many of the stones and bowlders submerged along the shores. The average density of the water was 1.006.

Six-Mile or Tellers Bay.—The name is due to the original length of this bay, which extends in the same direction as Creel Bay and is of the same general character. Soundings show a maximum depth of 10 feet, shoaling gradually to the muddy and weed-grown northern end. The density on July 23, 1907, was 1.0056.

Mission Bay.—This part of the southeastern portion of the main section of the lake has only a fraction of its original area. It extends south by west for about three-fourths of a mile, with a breadth one-half as great, and nearly surrounded by high, wooded, morainal hills; is landlocked in all directions except the north, where its entrance has a width of 463 feet and an average depth of not over 3 feet, with a channel 5½ feet deep and about 10 feet wide. The total area approximates one-third of a square mile. The deepest water in the bay is 11½ feet, shoaling uniformly in all directions to the shores.

Mud flats, very soft and yielding, with underlying black soil, fringe its southern extremity and sustain tall rushes and cat-tails, at the water's edge two years ago, but now 15 feet or more from the shore line. All remaining shore, where not lined with rushes or soft yielding mud, has a gravelly beach. A species of waterweed (*Ruppia maritima*) is found growing uniformly throughout the bay. Fresh water from Court or Spring Lake, one-eighth mile distant, seeps through the rushes into the southern end of this bay. The density of the water was found to be 1.0058, the temperature 68° F.

This, perhaps, is the best part of the main section for the introduction of suitable fish, owing to its protection from storms, its narrow entrance easily guarded by a gate, the character of its bottom, the depth, and the seepage of fresh water from the neighboring Court or Spring Lake. A supply of young large-mouthed black bass and catfish were introduced here during the investigation.

EASTERN SECTION.

Devils Lake, south of Lake and Minnewaukan townships, presents the same conditions as appear in the section just described. It is of an irregular shape, its length from the southern extremity of Roque Island to Lamoreau Bridge is approximately 15 miles, and its greatest breadth 3 miles.

In general the bottom is muddy and at a uniform depth of 12 feet. The eastern portion is rapidly shoaling, and it was only with difficulty that the passage could be made with a gasoline launch drawing about 15 inches of water. Soft black mud, bearing a growth of weeds that continually checked the progress of the boat, was found to extend from shore to shore east of the Odessa Township line.

Minnows and sticklebacks (*Pimephales promelas* and *Eucalia inconstans*) constitute the fish life and afford a plenteous supply of food for the great flocks of sea gulls and terns. Many species of ducks are numerous.

Temperature and salinity observations were made at frequent intervals, but no essential variation noted. The surface temperature averaged 70° F., the density 1.009.

LAMOREAU BAY.

This is a beautiful sheet of water extending in a southeasterly direction for 6 miles, with a maximum width of about 2 miles. The shore line does not exhibit the irregularities of other sections. The density of the water was 1.008, the temperature 70° F.

WESTERN SECTION.

This broad section formerly extended from La Rose Ferry, at the eastern end of the United States reservation on Grahams Island, westward to Minnewaukan, 11 miles distant. The area to the west of Grahams Island is now dessicated and covered by a growth of wild grass and weeds, with a narrow channel, not deeper than 3 feet, running northerly to the northwestern extremity of the island toward the old course of the Mauvaise Coulée. The drying up of the straits at Spaldings Ferry and at a point midway between there and the mouth of the coulée forms two small detached bodies of water, the remnant of the tributary arm of this section. Only skiffs or gasoline launches with a draft of 18 inches or less can pass through this portion of Devils Lake. The bottom consists of soft black mud, 2 to 3 feet deep, sustaining a growth of weeds that continually entangled the propeller, forcing frequent halts. The greatest depth found was 7 to 8 feet, the average 3 feet.

The shores along the southern margin of Grahams Island consist of wide mud flats, in many localities over 50 feet in width, but the southern shore presents a narrower stony littoral and a nearer approach to the conditions found in the main section. The average density of water was 1.005 and temperature 74.3° F.

WATERS ADJACENT TO DEVILS LAKE.

To determine the conditions obtaining in neighboring lakes relative to the character of the water, fauna, flora, and other factors important in the study of fish life, brief examinations were made of the following:

Court or Spring Lake.—This is a small sheet of fresh water situated one-eighth mile from Little Mission Bay beyond the roadway and its western bank and inclosed on all sides by wooded hills which protect it from storms that sweep Devils Lake. Its area is approximately one quarter section. No bottom soundings could be made, but a depth of 8 feet and over was found by one of the members of the party swimming about and "sinking." A muddy bottom was found in the center. Small stretches of sandy shore here and there alternate with the rushes and aquatic plants that protect the littoral. Shrubbery and woods approach the water's edge and uncultivated land surrounds this beautiful sheet of water hidden among the hills. The temperature found July 25, 1907, at 11.30 a. m., was 73.5° F., the density being 1.000.

No recession of the water was noted, and there were no evidences of the conditions obtaining in the big lake situated but a few rods away. The lake is fed by bottom springs, its level is 20 feet above

that of Devils Lake, and its fresh water seeps down through the rushes into the southern end of Little Mission Bay.

Many forms of insect life were noted here, aquatic beetles, larvæ, and crustaceans being numerous. Minnows with nuptial tubercles have been identified as the same species inhabiting Devils Lake. Sticklebacks (*Eucalia inconstans*) were also taken, and many tadpoles were observed swimming about.

In general the lake appeared favorable as a breeding pond for black bass, perch, and allied species. With the elevation, the proximity to Mission Bay, the character of the water, and the source of supply, it would not be a difficult task to construct a runway connecting the two bodies of water.

Sweetwater Lake.—This lake, situated 5 miles north of Devils Lake city, in Freshwater and Morris townships, is of irregular shape and its area approximates 11.5 square miles. Sweetwater Inlet, a coulée of considerable size, with branches rising in the northern regions of Ramsey County, enters the lake at its eastern end in Morris Township. From the northeastern end, in Freshwater Township, connection is maintained with Dry Lake by a creek 4 miles in length. The average depth is 7 feet; the maximum, 17 feet. The bottom consists almost wholly of soft mud, sustaining an abundant growth of water milfoil (*Myriophyllum verticillatum*) and pondweed (*Potamogeton pectinatus*), the latter predominating. In many spots the mud is from one-half to 1 foot deep. The shores consist of stretches of rushes, gravel, and a few bowlders, 80 per cent of the littoral being lined with rushes.

As in the case of Devils Lake, this lake is gradually diminishing and breaking up into detached bodies, changes shown by the white alkaline deposit on the lands surrounding the lake, and more strongly by the natural levees and terraces that skirt the shore. The water level is constantly fluctuating, and according to good authority the banks were overflowed during the spring of 1906. In 1889, the "dry year," the lake level dropped until the several passes were frozen dry, but, according to the same authority, not dry enough to kill fish.

Though Sweetwater Lake has thus been shown to possess a number of characters similar to Devils Lake, it is important to emphasize the conditions more favorable to fish life and unlike those obtaining in Devils Lake. From this lake the town of Devils Lake obtains its water supply, the water being soft and good for drinking purposes and steam making. Salinometer tests show it to be perfectly fresh.

Minnows and sticklebacks and aquatic insects, the same species as in Devils Lake, were taken in abundance with seines. Young bass, introduced by the Bureau of Fisheries one month prior to this examination, were captured and found to be in excellent condition.

Dry, Cavanaugh, and the Chain lakes.—About 5 miles to the north of Six-Mile Bay lies Dry Lake, which maintains connection with the Chain Lakes on the northwest and Sweetwater Lake on the east by coulées opening into its upper portion. It extends from north to south for approximately 6 miles, the northern half attaining a breadth of 2 miles, the remainder being 1 mile or less in width. This lake was not visited, but it is reported that a man can easily wade throughout its northern half, while the southern half averages 7 to 8 feet in depth. The lake practically freezes dry in winter. The water is said to be slightly brackish, containing a very small percentage of alkali. There are no fish.

Cavanaugh Lake, a small body of water northwest of Sweetwater Lake, is exceedingly shallow, contains no fish life, is frozen dry in winter, and is considered of but little importance.

The Chain Lakes, consisting of Lake Irvine, Lac Aux Morts, and Twin Lakes, form a series of small-sized, irregular-shaped bodies of water in close proximity and connected by coulées. These lakes are shallow, with muddy bottoms and surrounded by marshes. The level of their water fluctuates under the influence of spring freshets or the evaporation of the summer, and in winter they are frozen dry. Their depth and the character of their shores render them favorable for spawning grounds during the spring and early summer. The water is reported to be fresh with but the slightest presence of alkali.

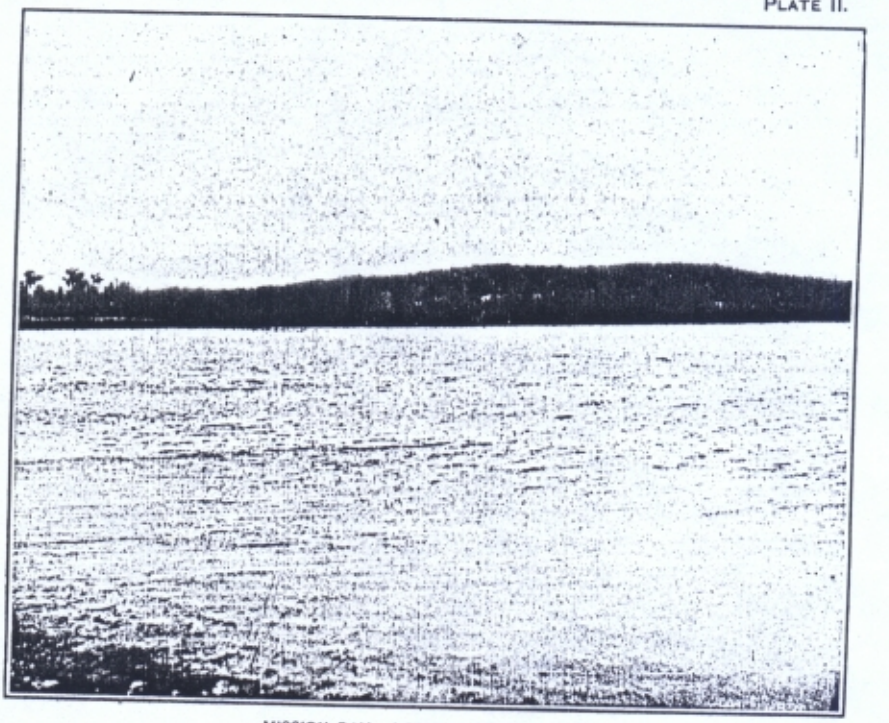
Wood Lake.—This beautiful sheet of water, located in the interior of the Sioux Indian Reservation about 8 miles from Fort Totten on the south shore of Devils Lake, is of irregular shape with a length of 1 mile and a breadth one-half as great. In general the shores bear rushes that in many localities extend far out into the lake, but there are short stretches of sandy beach favorable for seining. The water, probably derived from springs, is perfectly fresh and suitable for all ordinary uses, and furnishes excellent fishing for yellow perch and pickerel, the former occurring in very great abundance. The small supply of yellow perch and pickerel obtained for the acclimatization experiments conducted at Devils Lake, described in subsequent pages, were seined from this lake. Minnows occur, but not abundantly. Black bass are reported to have been introduced, but none were captured.

PHYSICAL CONDITIONS.

FLUCTUATIONS OF LEVEL.

A study of the fluctuations of the level of Devils Lake is essential to an understanding of conditions relative to the disappearance of food fish in 1889 and possible future efforts at restocking.

Devils Lake lies in a region where there is but little rainfall and the evaporation is greater than the precipitation. This condition is force-



MISSION BAY. LOOKING SOUTHWARD.

SOUTHERN SHORE OF MISSION BAY.

fully shown by a study of the normal precipitation records, compiled by Mr. E. J. Glass, observer, United States Weather Bureau. From these it may be noted that in 1905 the rainfall amounted to but 18.5 inches, and this scanty amount had not been equalled at the close of the present investigations in September, 1907, though May, June, and July are the months of the greatest rainfall.

From July 20 to September 10, 1907, comprising seven weeks, the level of the lake dropped approximately one-half foot. Observations of the fluctuations of level were made from a tide gauge established by the Geological Survey in 1883. At the beginning of the period mentioned the lake-level reading was 12.3, at the close it was 11.85.

At the time of the observations at Devils Lake by the Geological Survey a permanent bench mark was established in the yard of Captain Heerman. This consisted of an iron post 3 inches in diameter, with a copper cap, driven into the ground. On the top of the cap was the inscription "U. S. Geological Survey B. M." and in the center a crosscut, as here represented:

Elevation above sea	
Datum.	Feet.

Beside the bench mark a painted wooden tablet reads: "This bench mark is 1,439.08 feet above the sea and represents height of lake in June, 1883. Zero of gauge 22.90 feet below bench."

Observations made by the Bureau of Fisheries party in August, 1907, disclose the fact that this bench mark was situated 143 feet from the present shore line and the level of the lake was found to be 1,428.6, approximately 10½ feet below that of 1883.

The following quotation from the monograph [a] on the Glacial Lake Agassiz by Warren Upham, pages 594–595, describes the fluctuations in level common to lakes of this region:

> Through the past hundred years maximum and minimum stages of the great Laurentian lakes have alternated in cycles of about a dozen years, during which comparatively scanty average rainfall for several years was followed by unusually abundant rainfall. These fluctuations are similar with those just noted in the rainfall of North Dakota. Besides such short cycles important secular changes of the mean annual precipitation in this State, occupying considerably longer periods, have caused remarkable changes in the levels of numerous lakes which have no outlets.
>
> Devils Lake thus shows evidence of having attained, about the year 1830, a level of 16 feet higher than its low stage in 1889, reaching at or near the former date to the line that limits the large and dense timber of its bordering

[a] U. S. Geological Survey Monograph XXV. The Glacial Lake Agassiz by Warren Upham. Washington, 1895.

groves. Below that line are only smaller and scattered trees, of which Capt. E. E. Heerman informed me that the largest found by him and cut a few years ago had 57 rings of annual growth. Within the twenty-five years since the building of Fort Totten this lake has fallen 9 or 10 feet, and it has fluctuated 4 feet under the influence of the changes in the average annual precipitation of rain and snow during the past dozen years.

The high stage reached by this lake about sixty years ago appears to have been limited by an avenue of discharge eastward into Stump Lake, which rose at the same time to within about 3 feet of this height. The latter and smaller lake, receiving no large tributary and lying in a basin that nowhere extends many miles from the lake, was prevented by evaporation from rising quite so high as Devils Lake, which, during years of abundant rains and snows, receives a large tributary, the Mauvaise Coulée, draining a broad area that stretches 60 miles northwestward to the Turtle Mountain. The outlet from Devils Lake into Stump Lake was nearly due eastward from Jerusalem, situated on Lamoreaux Bay at the most eastern portion of the entire lake shore. With an overflow at this point, Devils Lake may many times have been raised to this beach by periodic variations in rainfall during the many centuries since the ice age.

At the time when the last ice sheet retreated, however, the confluent water of Devils and Stump lakes were raised to a shore line which now has a slight ascent from west to east, lying 21 to 25 feet above the low stage of Devils Lake in 1889. This shore is traceable around both lakes, passing above the watershed that now divides them.

From the same authority are taken the following notes on elevation:

	Feet above the sea.
Devils Lake, surface of water, August 8, 1887	1,431.6
Devils Lake, surface of water, in 1889	1,430
Devils Lake, highest and lowest stages during the years 1880 to 1889	1,434–1,430

From notes of investigations:

Devils Lake, bench mark, U. S. G. S., June, 1883	1,439.08
Devils Lake level by Bureau of Fisheries, August 21, 1907	1,428.6

By these figures it will be observed that Devils Lake rose 5 feet between 1880 and 1883, attaining its highest level, 1,439.08 feet, in the latter year. Since then it has diminished steadily, dropping 9 feet in the succeeding six years and 1½ feet since the "dry year," 1889. The lake at present is at its lowest, and it is doubtful whether any maximum seasonal fluctuation can cause it to attain the level of 1889. It is a matter of common knowledge that bays and tributaries navigated by steamers in 1883 are now entirely desiccated or closed to navigation. At that time the main body of the lake was reported to have a depth of 35 feet. Soundings made in August, 1907, by the Bureau of Fisheries, show a maximum depth of only 25 feet.

In considering these data the apparent significance of plowed land in connection with the drainage and precipitation must not be overlooked. The recent lowering of the lake level has obtained

during a period of rapid development of the surrounding farm lands, which absorb a considerable part of the precipitation. The destruction of spawning beds by the drying of Souris or Mouse River as the result of cultivation of its banks is generally conceded to be one of the principal causes for the disappearance of fish from the waters of Devils Lake.

TEMPERATURE RECORDS.

During the investigations described by this report daily observations were made of the air and water temperatures from July 26 to September 4, 1907. Readings were made at 8 a. m. and 8 p. m. during July, and at 8 a. m. and 7 p. m. during August and September. The results of these observations, briefly tabulated, are:

Dates (inclusive).	Average temperature of air.		Average temperature of water.	
	8 a. m.	*8 p. m.*	*8 a. m.*	*8 p. m.*
July 26-31	64.32	70.0	69.83	72.75
August 1-15	62.8	71.0	67.0	*7 p. m.* 68.73
August 16-31	59.37	68.18	63.62	65.28
September 1-5	56.0	*7 p. m.* 68.3	52.66	66.0

Other observations were made at irregular intervals, both in time and locality, during the examination of the lake, especially when running lines of soundings.

From the maximum and minimum thermometers set up at the headquarters of the party the following averages were obtained. Readings were taken daily at 7.30 p. m., and the instruments were placed in a protected position:

Dates (inclusive).	Average daily minimum temperature.	Average daily maximum temperature.
July 26-31	55.5	78.2
August 1-15	52.0	74.43
August 16-31	50.9	75.1

The lowest temperature recorded was 42°, the highest 88°.

The importance of temperature in relation to fish culture and maintenance can not be overestimated. In the Devils Lake region the difference between the mean temperatures of summer and winter is very great, the winters being very cold and the summers, in part, hot. During the months of July and August the mornings and nights are cool, the midday delightful. In winter the temperature is continuously below zero (Fahrenheit), but the dryness of the air makes the extreme cold (0° to —43°) more endurable than the higher temperatures of a more humid region.

Ice commences to form about the middle of November and remains until the middle of April. Mr. E. J. Glass, the observer of the Weather Bureau at Devils Lake, states that the main body of Devils Lake will not freeze solid, 4 feet being considered a good estimate of the thickness of ice formed, which is more or less porous, with big cracks, often 3 feet wide. During the warmer days the ice in expanding closes the cracks and, bending downward, forms V-shaped grooves, or upward, solid walls. The intense dry cold, according to the same observer, will often cause the ice to evaporate without liquifying, and ice walls thus formed have been observed gradually to disappear.

QUALITY OF WATER.

In June, 1906, with a view to ascertaining whether the water of Devils Lake was injurious to fish life, and, if so, to what extent, Messrs. C. M. Fisher and Charles E. Taylor, residents of the community, forwarded to the Bureau of Fisheries for analysis 2 gallons of water from Creel Bay.[a] This specimen was submitted to the Bureau of Chemistry, which furnished the following report:

ANALYSIS 3064 MISC.

	Parts per million.
Calcium	29.66
Magnesium	452.48
Sodium	2,118.50
Chlorine	821.84
Sulphuric acid ion	4,345.84
Carbonic acid ion	119.16
Bicarbonic acid ion	629.82
Total	8,517.3

HYPOTHETICAL COMBINATION.

	Parts per million.
Calcium bicarbonate	119.8
Magnesium bicarbonate	647.6
Magnesium carbonate	167.0
Magnesium sulphate	1,470.0
Sodium sulphate	4,758.9
Sodium chloride	1,354.0
Total	8,517.3

The water of Devils Lake possesses many qualities that render it unsuitable for drinking and for engine boilers, etc. It is reported that in former years, before the level of the lake dropped to its present plane, it was quite generally used for drinking, but at present this is not the case, though cattle are said to drink freely of it. The

[a] The analysis given above may be compared with that of 1907, station No. 4, on page 14.

writer found the water to be slightly brackish, though not disagreeable, and when used for cleansing purposes it was satisfactory, though soap will not produce a lather with it.

In order to determine to what extent the water varies in the several representative portions of the lake, samples were obtained from the stations shown upon the chart accompanying this report. Following are the results of the analyses, the specimens being designated by the laboratory numbers of the Bureau of Chemistry:

ANALYSES OF WATERS OF DEVILS LAKE, NORTH DAKOTA, 1907.

[Parts per million.]

Description.	Station 2, off mouth Creel Bay. (4838)	Station 4, off wharf Creel Bay. (4840)	Station 3, Mission Bay. (4839)	Station 5, Large Lake. (4841)	Station 1, Six-mile Bay. (4837)	Station 6, East Lake. (4842)
Carbonic acid ion	107.8	108.1	119.2	125.1	128.7	154.9
Bicarbonic acid ion	495.4	499.9	527.4	538.9	546.5	555.6
Silica	20.8	21.0	23.0	26.6	37.8	44.0
Chlorin	856.8	866.8	876.1	900.3	906.1	1,122.0
Iron	7.1	9.9	11.0	14.8	15.3	16.4
Calcium	18.6	22.9	24.9	26.3	31.0	31.2
Magnesium	493.8	504.3	509.2	530.5	545.5	601.6
Sulphuric acid ion	4,654.0	4,774.6	4,856.9	4,977.9	5,206.0	6,254.4
Sodium	1,987.8	2,030.3	2,075.0	2,108.3	2,193.8	2,725.3
Potassium	186.2	187.8	195.7	199.7	204.7	250.0

HYPOTHETICAL COMBINATION.

[Parts per million.]

Description.	Station 2, off mouth Creel Bay. (4838)	Station 4, off wharf Creel Bay. (4840)	Station 3, Mission Bay. (4839)	Station 5, Large Lake. (4841)	Station 1, Six-mile Bay. (4837)	Station 6, East Lake. (4842)
Potassium chloride	354.8	357.9	372.9	380.5	390.5	476.4
Sodium chloride	1,135.7	1,149.7	1,153.3	1,187.3	1,189.5	1,478.4
Sodium sulphate	4,749.5	4,863.9	4,907.7	5,058.8	5,319.7	6,607.8
Magnesium sulphate	1,810.8	1,865.4	1,855.5	1,955.1	2,020.0	2,243.0
Magnesium carbonate	151.6	152.0	167.6	179.9	181.0	217.8
Magnesium bicarbonate	503.0	498.7	513.2	505.9	508.0	511.4
Calcium bicarbonate	75.2	92.6	100.7	106.3	125.0	126.1
Ferrous bicarbonate	22.6	31.5	35.0	47.1	48.7	52.2
Silica	20.8	26.6	23.0	21.0	37.8	44.0

Considerable variation may be observed in the chemical character of the water in the several portions of the lake.

For a general understanding of the significance of these analyses given above the explanation of the term "alkali" may be useful. An "alkali" is a compound of hydrogen and oxygen with any one of the metals—lithium, sodium, potassium, rubidium, cesium, or the radical ammonium. The alkalis are all soluble in water and are capable of neutralizing acids and turning red litmus blue. Aqueous solutions of the alkalis of moderate strength act corrosively upon animal and vegetable substances. Two main classes may be distin-

guished in connection with soils: "Black" alkali, in which sodium carbonate predominates, and which is on this account highly corrosive and injurious to vegetation; and "white" alkali, the predominant constituent of which is sodium sulphate, and which is much less harmful to plant growth. Both when present in considerable quantities, by their interference with osmotic action (the process by which seeds and plants take up moisture from the soil), prevent or retard germination and growth. It will be observed that sodium sulphate or "white alkali" is the principal constituent of the water of Devils Lake. Epsom salts (magnesium sulphate) and common salt (sodium chloride) are next in quantity and occur in almost equal proportions.

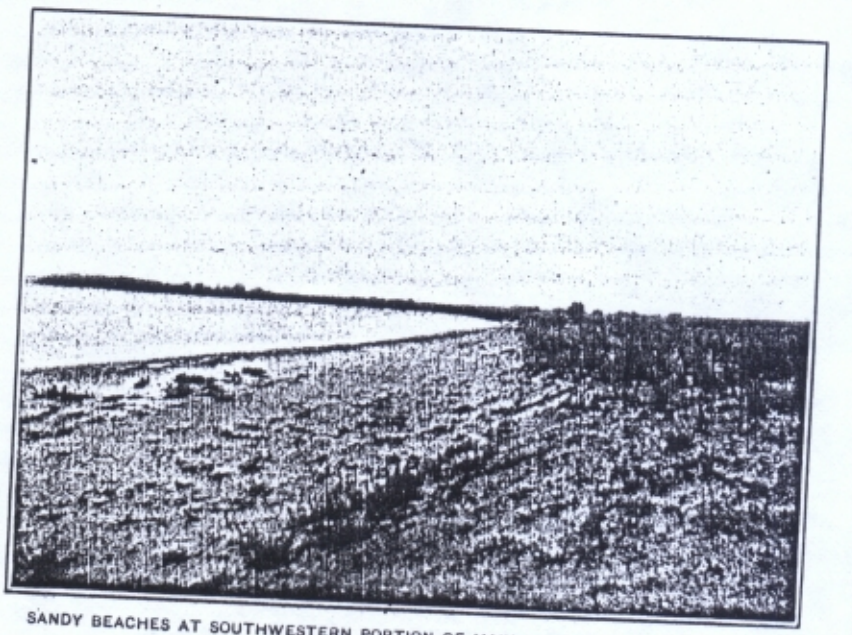
Though the analyses here given disclose the presence of alkaline salts (not free alkali) in relatively high percentage, it can not be assumed that these contained solids in these proportions are necessarily prohibitive to the acclimatization of certain species of fish. The action of this water on introduced fish can be determined by experiment; whether it is deleterious has not been fully demonstrated.

The pebbles and bowlders strewn along the shores of the lake are, as mentioned in earlier portions of this report, wholly or partly encrusted with a white deposit of alkali. Nearly all of the surrounding lands, especially the "dried-up" bays, show upon their surface a thin grayish-white efflorescence resembling frost. These accumulations, generally found in regions of deficient or irregular rainfall when the soil contains unusually large amounts of soluble salts concentrated in or near the surface, represent the residue from the evaporation of moisture.

In fact, the scanty vegetation of the lake shores furnishes strong evidence of the character of the water. As is well known, alkali lands are commonly either entirely devoid of vegetation, or else produce plants of little or no value to man. Slowly, but surely, exposed portions of the basin of the lake are being reclaimed for agricultural purposes after a thorough drainage for several years. The presence of a small amount of alkaline matter in the surrounding higher lands contributes advantageously to the resultant harvest. The more recently exposed portions of Devils Lake are barren or overgrown with a scant growth of wild grasses possessing a marked tolerance to alkali and serving as an excellent index, therefore, to the nature of the underlying soil.

Specific gravity.—Observations of the density or specific gravity of the water were made throughout the period spent by the party at Devils Lake, the salinometer and salinometer cup adopted by the Bureau of Fisheries being used for the purpose. Fresh water is considered as 1.000 on a scale ranging from 1.000 to 1.031, sea water registering about 1.025.

BOWLDERS INCRUSTED WITH ALKALI, ON SHORE OF DEVILS LAKE.



SANDY BEACHES AT SOUTHWESTERN PORTION OF MAIN LAKE, NEAR "MILE SIGNAL.

The water at Devils Lake was found to vary from 1.0054 to 1.009, according to locality. Detached bodies, like Mission Lake, especially when surrounded by developed lands, were, for obvious reasons, found to possess the higher densities. The lowest, 1.0054, was observed in Mission Bay, and is to be accounted for by the seepage of small quantities of fresh water from Court or Spring Lake. The average density of the main portion of the lake was 1.006.

BIOLOGICAL FEATURES.

The fauna and flora of Devils Lake are found to have an important bearing on the subject of the present investigation, and demand consideration at this point. Collections were made of the life of the lake, both zoological and botanical, including the plankton, and notes were gathered on all facts relating to the cause of the paucity of fish.

But two varieties of fishes were found, a stickleback (*Eucalia inconstans*) and a minnow (*Pimephales promelas*), which were obtained in abundance, both in frequent hauls of the seine and by a crude but effective trap constructed by one of the party. They were taken literally by the hundreds and without use of bait in any way. The sticklebacks were generally large in size and of a uniform black color, though specimens of a lighter color and mottled appearance were numerous. Often many were seen swimming close to the surface, and, possessing but little activity, were easily captured by hand, while they were seen to be caught by the thousands by gulls and terns. A good proportion of the minnows secured bear nuptial tubercles, with brighter dashes of color; the heads and lateral bands were black.

Prior to 1889 Devils Lake teemed with pickerel, probably *Esox lucius*. Observations upon their abundance and size and the cause of their disappearance are reserved for special mention.

The batrachians were represented by two species, the hellbender (*Cryptobranchus alleghaniensis*) and the leopard frog (*Rana pipiens*). Both were abundant, the former constituting the principal food of the cormorants. In this connection it may be stated that on visiting the "Rock Pile," a small rocky island in the main section of the lake, used as a rookery by cormorants and a few white pelicans, the food disgorged by frightened birds was found to be composed entirely of sticklebacks and young hellbenders. One of these food piles contained 18 and 13 of these animals, respectively, the hellbenders all under 3½ inches in length. Fully 100 nests and 500 birds were counted on this island. Leopard frogs were everywhere abundant along the shores. No turtles are known to occur in the lake.

Muskrats are occasionally seen, and bird life was well represented. During the investigations in this region over fifty species of birds were listed. Immense flocks of black-headed or laughing gulls

(*Larus atricilla*) and common terns (*Sterna hirundo*) rear their young on the rocky shores and islands of the lake and feed upon the sticklebacks and minnows. A few great gray sea gulls (*Larus marinus*) were observed associating with the black-headed form. Flocks of black terns (*Hydrocheilidon nigra*) were not uncommon, being generally seen flying over the marshes and weed-grown portions of the lake. Along the shores many forms of sandpipers, killdeer, and allied forms were numerous, feeding on the exposed muddy flats, and snipe were at all times abundant. Hell-divers, loons, and ducks were everywhere to be seen.

The flora of the lake is exceedingly scanty for reasons already indicated. All or nearly all of the shallower waters contained a species of waterweed (*Ruppia maritima*). The shores are practically devoid of vegetation, though wild flowers of the hardier northern varieties flourish profusely on the prairies and pastures sloping downward to the lake.

Both the plankton and tow nets gave fruitful results. Towings made along the shore and off the wharf of the Chautauqua grounds revealed a remarkable supply of microscopic forms. Towings at and below the surface of the water for periods of but one minute yielded three liquid ounces, principally of copepods (*Diaptomus pallidus*). A few small water bugs (*Notonecta* sp.) and amphipods occur. The abundance of life varies, as is to be expected, throughout the lake system, the weed-grown shallow portions of the shores and bays yielding the richest returns. In the more protected waters of the lake the minute life could be seen with the eye, darting among the rank, coarse vegetation, literally by the millions. Vertical hauls were made with the plankton net during the course of the hydrographic work at stations in various portions of the lake, the stations being located by the same methods employed for obtaining water specimens. The results of all hauls proved satisfactory.

The importance of these minute living organisms must be considered carefully in relation to the presence of minnows and sticklebacks. The food of young fish in general includes insects—adults and larvæ—worms, mollusks, crustaceans, smaller fish, fish eggs, and vegetable matter. The part that the plankton crustacea play is important.

DISAPPEARANCE OF PICKEREL.

From all information available it appears that prior to 1889 Devils Lake was well stocked with pickerel. This was, perhaps, an influential factor in the selection of a reservation on its shore by the Sioux Indians, and also in the influx of peoples of Scandinavian origin.

According to excellent authorities, these fish averaged from 5 to 6 pounds, a number of 17 or 18 pounds weight were caught, and one

specimen, displayed in Devils Lake city, weighed 19 pounds. The average length was about 2 feet, the largest measured 3 feet, and those under 7 inches were rarely seen or caught. The flesh was reported to be firm and of fine flavor. No other species of fish was known to have been captured from this lake.

No special attention seems to have been given to the protection of the pickerel and they were caught at all seasons of the year. Lured by artificial minnows weighted and controlled by a cord, the pickerel were speared as they seized the bait. Holes were cut in the ice to continue this practice in winter. It was the most efficient and common method of capture, though the spoon hook and bright-colored cloths were also employed with success.

Though abundant in all portions of the lake, nearly all of the fish were caught in the bays or tributaries of the main lake, and Creel Bay was the principal fishing ground. Devils Lake city was located on the northern shore of that bay and between the town and the "Narrows"—now the northern limit of the bay—the extensive area then existing formed the favorite spawning ground for pickerel. To this point in spring the fish would run through the narrows, where they were speared by thousands. At one time fifty shacks for the fishermen were located in that locality. Where the depth of water was then 6 to 7 feet and the width of the narrows approximately 300 yards, brown, dried-up, barren lands and broad wastes of weeds with incrustations of alkali now cover the famous fishing and spawning grounds.

The abundance of the fish may be deduced from the facts that the United States agent at Fort Totten purchased at one time two carloads of pickerel for shipment; that a butcher of Devils Lake city received also at one time two carloads, and finally the same man held during one season a standing order for 1,200 pounds daily. The fish received were in excellent condition. Pickerel occurred in greatest abundance during the years 1884–1887, and the last ones received were caught by an Indian at Fort Totten in 1889.

Many theories have been advanced to account for their mysterious disappearance, but none is sufficiently supported by the evidence. Destructive fishing methods, the corrosive effect of lake water, desiccation of spawning beds due both to meteorological causes and absorption of precipitation by plowed lands, and even the possibility of underground outlets to the lake have been adduced as explanations.

The following facts, however, merit consideration. The former connection of Devils Lake by the Mauvaise Coulée with the Chain Lakes and ultimately with Dry and Sweetwater lakes has been described in previous pages of this report. During the years 1884 to 1887 Mauvaise Coulée was running throughout the entire year and

in 1888 until the fall. In 1889 it was completely dried up. The water of the coulée was much fresher prior to that time, and pickerel were often observed entering it, headed northward. Mr. Charles E. Taylor reports that in 1888 he "discovered pickerel by the wagon loads dead along the shores and sloughs at the south end of Dry Lake." He affirms that they perished because the lake "froze dry," and Lake Irvine, Lac aux Morts, Dry Lake, and Sweetwater Lake were also reported to have been frozen dry in 1889. It thus appears that the retreat of the migrating fish was completely cut off by the drying up of Mauvaise Coulée. The extent of destruction to fish by the freezing of Sweetwater or the Chain Lakes could not be ascertained. The influx of considerable fresh water to these lakes, and the more favorable conditions offered for spawning purposes were without doubt impelling causes for migration. The loss of extensive spawning areas in Mission and Creel bays, the decimation of their species by overfishing, and the increasing alkalinity of water in Devils Lake contributed to the extensive migration and extermination.

The appearance of pickerel with slimy eyes and scales, as also those bearing sores or injuries, as reported by certain reliable persons, are conditions not infrequently found in fish of advanced age or in spawning individuals. Sufficient evidence could not be gathered to support the theory of any fish disease. All specimens captured during the closing years of their presence were observed to be in healthy condition.

ACCLIMATIZATION EXPERIMENTS.

During the period of the investigations at Devils Lake, observations were made upon several species of food and game fishes introduced and held in control for the purpose of determining respectively their adaptability to the water of the lake. These experiments were of varying character and yielded gratifying results.

Pickerel (*Esox lucius*), suckers (*Catostomus commersonii*), catfish (*Ameiurus nebulosus*), yellow perch (*Perca flavescens*), and large-mouth black bass (*Micropterus salmoides*) were experimented with. Attempts to construct fences of galvanized wire cloth and thus pen in the fish under experiment were found impracticable, and live cars of the same material were adopted.

On August 9, 7 suckers and 3 pickerel, all of good size, were confined in a live car measuring 12 by 8 by 6 feet, the frame constructed of 2 by 4 timber, and the sides of 1-inch wire mesh. The fish were seined from the Cheyenne River, at a point 20 miles from the North Dakota Chautauqua grounds. The car was buoyed, resting on the bottom, on the eastern shore of Creel Bay, but a few

rods distant from camp headquarters. The fish when introduced into the car were in excellent condition and manifested no dislike to their environment. On August 12 and 13, when examined, all the fish were in good condition, having withstood a severe storm on the 11th. On August 14 the 3 pickerel and 1 sucker were found dead, with no external or internal injuries to account for the mortality. The remaining suckers were found dead in the car on the 16th, and again no apparent cause for death was observed.

On August 16 a supply of about 300 yellow perch, from 1 to 7 inches long, were obtained from Wood Lake and placed in the live cars. No appreciable mortality occurred among them, the fish were at all times noted to be in excellent condition, and on the departure of the Bureau of Fisheries party September 10 all were healthy and active. Up to October 30 no mortality had been reported, and the perch retained for observation were in good condition.

Through the Bureau of Fisheries on August 27 Mr. C. M. Fisher received a consignment of young black bass and catfish. From this supply a number of both species of fish were retained for observation, and cars of one-fourth inch wire cloth were utilized for their control, the remainder of the fish being released in the lake. With the exception of a small number that were in weakened condition on their arrival, all bass have thrived under the confinement. Fully 95 per cent of the young bass were observed September 10 to be in active, healthful condition. The small number retained for continued observation were reported October 30 to be in excellent condition. Minnows and sticklebacks were provided for food.

A fine large specimen of pickerel, collected September 8 from Wood Lake, was found dead at the bottom of the live car September 10. An examination failed to disclose any injury or diseased organs.

Of the catfish received August 27 a few specimens were retained for control purposes, and these were found to be active September 10.

From the above it may be seen that no deleterious effects of Devils Lake water were to be observed on the yellow perch, black bass, or catfish during the period of confinement, and the same specimens are reported to be at this time in good condition.

SUMMARY AND RECOMMENDATIONS.

The physical and biological features of Devils Lake and its neighboring waters, together with data regarding the disappearance of pickerel and its probable cause, have been presented for a general understanding of the conditions in that region. Experiments on the suitability of a number of species of fish for introduction in the lake have also been described.

It has been shown that the entire system of Devils Lake waters has been gradually diminishing, owing to deficient precipitation and the development of the surrounding territory. This lowering of the lake level and the consequent desiccation of lake areas has been especially marked since 1883, and at present the lake appears at its lowest known level. Records of former years indicate that the level of the lake fluctuates to a considerable extent and a substantial increase may occur at any future date, but in view of the deficient precipitation disclosed by recent records for this section, the increasing development of surrounding territory, and the history of the lake for the past twenty-five years, it is extremely doubtful whether it will ever regain its former level.

The excessive evaporation has caused the loss of vast spawning and feeding grounds for the pickerel that formerly occurred in the greatest abundance. The disappearance of these fish and the reason for their migration to the shallower northern lakes, where thousands perished, is probably connected with the loss by desiccation of the grounds formerly favorable for their spawning. Exhaustive fishing and the increasing alkalinity of the water were contributory factors.

The stocking of Devils Lake with suitable food or game fishes under the existing conditions is not impracticable. Experiments conducted with yellow perch, black bass, and catfish were highly satisfactory. These species of fish were held in control in sections of the lake exposed to both favorable and unfavorable conditions for a period of two and one-half months and no deleterious effects were observed. It is therefore possible to introduce these or allied species of fish into Devils Lake with expectation of success, but care should be exercised to confine any introduced fish in the more favorable sections of the lake until tangible results of their propagation be manifested. Mission Bay, for example, may be mentioned as favorable. An effective dam and gateway can be constructed at the entrance at a moderate cost, also a culvert or runway leading from Court or Spring Lake to convey fresh water from the higher altitude of that lake. Court or Spring Lake in itself offers a favorable breeding pond for the selected varieties of fish.

Wood Lake is a favorable source of supply for yellow perch, and can be seined without difficulty, especially in its northwestern portion.

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